

# Test and Evaluation of WiMAX Performance Using Open-Source Modeling and Simulation Software Tools

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*Recently, various efficient WiMAX quality of service–based uplink scheduling algorithms have been proposed. These algorithms have been analyzed theoretically and in many cases evaluated unilaterally using ad-hoc random simulation. A novel integration of open-source and freeware modeling and simulation software tools for performing comparative analysis of uplink scheduling algorithms is presented. This integrated open-source modeling and simulation solution is used to evaluate the effect on performance of various uplink scheduling algorithms within a real-world quality of service–constrained tactical-edge scenario.*

**Key words:** IEEE 802.16; M&S; network simulation; open-source; QoS; uplink scheduling; WiMAX.

The Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard (IEEE 2004; IEEE 2006), also known as Worldwide Interoperability for Microwave Access (WiMAX), includes specifications for fixed and mobile broadband wireless access (BWA). Deployment of WiMAX is particularly attractive in tactical military settings where “cells” of high-data rate wireless connectivity must be established rapidly and relatively inexpensively (see *Figure 1*).

The 802.16 standard prescribes several quality-of-service (QoS) classes, which help ensure the reliability and timeliness of critical tactical edge (TE) applications such as voice over internet protocol (VoIP), real-time situational awareness (SA), and command and control (C2).

A typical configuration for WiMAX, called point-to-multipoint (PMP) mode, involves two types of communication stations: (a) base station (BS) and (b) subscriber stations (SS). The BS (perhaps located at the command center) regulates all communication in the cell network. Data are transmitted from the SS to the BS in the uplink direction and from the BS to the SS in the downlink direction. Sagacious allocation of available bandwidth “slots” in the uplink direction is crucial to QoS of WiMAX at the TE.

The amount of bandwidth each SS is allowed to have in the uplink direction is dynamically determined by the BS in the form of an “uplink scheduling algorithm” (Khalil and Ksentini 2007; Belghith and Nuaymi 2008). This algorithm is not specified in the

802.16 standard, thus giving WiMAX implementers the option of choosing, or even designing, optimized uplink schedulers that meet specific needs. For instance, one may seek to maximize the system throughput while maximizing the number of transmitted data packets with hard deadlines. An efficient uplink scheduling algorithm at the TE should consider the QoS constraints imposed by characteristic TE application traffic while seeking to maximize the throughput of the system (Yu 2008; Pishdad and Rabiee 2008; Piro et al. 2010; Wongthavarawat and Ganz 2003; Mohammadi, Akl, and Behnamfar 2008b).

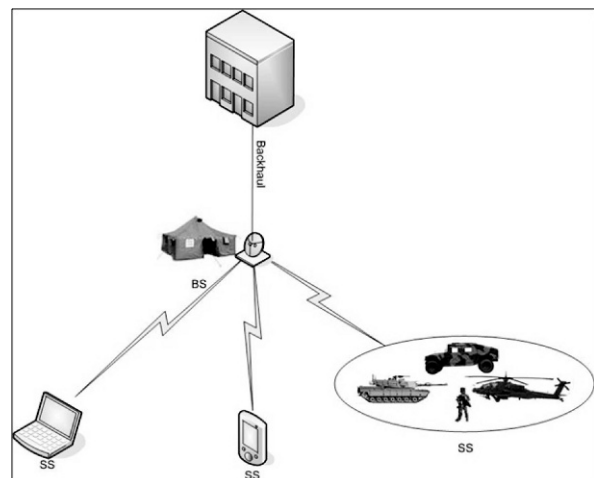


Figure 1. Simple tactical-edge Worldwide Interoperability for Microwave Access (WiMAX) depiction.

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## Approaches

Test and evaluation (T&E) of WiMAX QoS using existing and proposed uplink scheduling algorithms requires an environment flexible enough to select and implement different uplink schedulers. A field test with physical hardware utilizing field-programmable gate arrays (FPGAs) with the ability to reprogram new uplink schedulers is theoretically possible. Currently, however, most equipment used for WiMAX field tests within the Department of Defense (DoD) do not contain FPGA components. In addition, few testers possess the requisite expertise with hardware description languages (HDLs) and programming tools in order to program FPGAs. Even given FPGA-endowed equipment, HDL tools, and programmer resources, field testing of alternative WiMAX QoS configurations and algorithms would be cumbersome and costly.

A more flexible, rapid, and cost-effective way to test and evaluate WiMAX QoS is to use discrete event simulation, a high-fidelity form of modeling and simulation (M&S). A discrete-event network simulator emulates the behavior of an interconnected network and applications, including detailed processing through all layers of the protocol stack. In the case of WiMAX, this should include an accurate media access control (MAC) and physical layer (PHY) implementation of the 802.16d and 802.16e specifications with PMP mode and the Wireless Metropolitan Area Network Orthogonal Frequency-Division Multiplexing (MAN-OFDM) PHY layer. These two specifications are also known as fixed and mobile wireless, respectively. Examples of network simulators that claim to accurately implement the 802.16d/e standards include ns-2/ns-3 (NSNAM), OPNET (OPNET Technologies, Inc.), and QualNet (Scalable Network Technologies).

Two important requirements for our T&E of WiMAX QoS with new and existing uplink scheduling algorithms are cost and modifiability. The two simulators ns-2 and ns-3 are open-source. For comparison, OPNET is proprietary software requiring the purchase of multiple licenses and support options at a current cost approaching \$60K. An integrated graphical user interface (GUI) is lacking in ns-2/ns-3, requiring C/C++ programming in order to configure the simulation. OPNET, on the other hand, possesses a mature and intuitive GUI for configuration.

Cost and ease of configuration aside, the greatest argument for using an open-source simulator is the ability to modify and add source code. T&E of existing and proposed uplink scheduling algorithms requires the ability to incorporate a significant amount of logic into the simulator that goes beyond simple configuration. Proprietary M&S tools may offer the user a limited ability to configure “built-in” algorithms or add

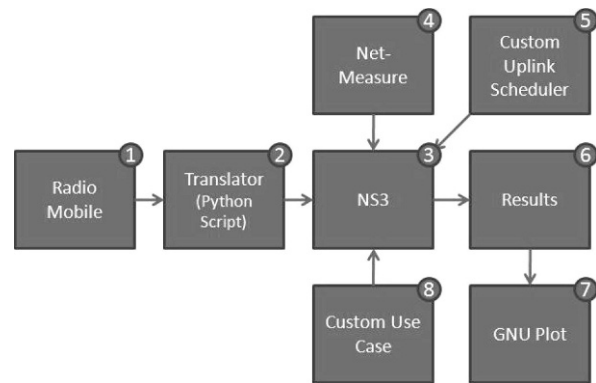


Figure 2. Integrated architecture.

some process code but often provide no mechanism to significantly modify existing algorithms or implement new algorithms. When such a provision is available, the modification or implementation of the algorithm is realized as C or C++ code.

## Solution components

We propose and utilize integrated solution architecture for T&E of WiMAX performance on QoS-constrained TE traffic (see Figure 2). The solution represents a loose coupling of five open-source and freeware software tools. We briefly describe each of the five tools in this section and, where relevant, address validation acquiresments.

### ns-3

The ns-3 simulator was selected because it is actively developed on multiple fronts, written entirely in C++, and has a rich set of WiMAX modules. Initial funding to develop ns-3 was provided, in part, by the National Science Foundation in 2006. Since then, the ns-3 development effort has attracted the support and interest of several major academic departments and organizations including the Electrical and Computer Engineering Department at the Georgia Institute of Technology, the Electric Engineering Department at the University of Washington, and the Google Summer of Code.

Ns-3 consists of a simulation core engine, a set of models, example programs, and tests. The ns-3 testing environment provides model validation and testing tools and encourages the publication of validation results. Characteristics of the ns-3 development effort include

- strict implementation of IEEE specifications;
- broad international use and contribution;
- continuous academic, corporate, and public scrutiny of the source code;
- academic “validation” through published articles and conference presentations; and
- extensive testing.

A search on the Association of Computing Machinery (ACM) portal for articles involving the keyword, “ns-3”, identifies nearly 500 articles. Searching with the additional keyword, “WiMAX” yields 20 articles spanning respected conferences such as SIMUTools, WICON, SIGOPS, SIGCOMM, AAA-IDEA Interperf, and ValueTools.

It is difficult to guarantee the correctness of large-scale software simulators, including commercial simulators. Rather, qualities such as those listed above build confidence in the simulator’s correctness, including validation and verification.

In the language of the ns-3 documentation (ns-developers@isi.edu 2010), “ns-3 must be correct, robust, performant and maintainable.” In summary, each of these test criteria is addressed as follows (with excerpts from the ns-3 testing documentation):

- Correct: “The ns-3 testing environment provides tools to allow for both model validation and testing, and encourages the publication of validation results.”
- Robust: “The ns-3 testing environment provides tools to allow for setting up and running test environments over multiple systems (buildbot) and provides classes to encourage clean tests to verify the operation of the system over the expected “domain of applicability” and “range of accuracy.”
- Performant: This is a concise neologism that is used to describe the design goal that ns-3 must be “powerful and fast enough to get the job done. In the ns-3 test framework, we provide support for timing various kinds of tests.”
- Maintainable: “The ns-3 testing framework provides tools for automating the process used to validate and verify the code in nightly test suites to help quickly identify possible regressions.” These regressions include local regressions, remote regressions, unmasked regressions, and performance regressions.

## Radio Mobile

As mentioned, ns-3 lacks a GUI. This condition not only diminishes usability but also denies the user the ability to graphically specify network topologies. A freeware tool called Radio Mobile (RM) (Coude n.d.) exists that predicts the performance of a radio system by using digital terrain elevation data. RM additionally provides a GUI for the layout of wireless network devices on top of a rendered topography. The output of RM can be used to configure ns-3 for more realistic scenarios, which include topology, distance, and signal properties.

RM is based on the U.S. Department of Commerce National Telecommunications and Information Administration Institute for Telecommunication Sciences (NTIA/ITS) Irregular Terrain Model (ITM) (Longley-Rice). This software has been in use since 1988. RM’s publication history is less extensive than ns-3, with only a few articles appearing in *Radcom* (Brown 2006) and *AntenneX* (Brown 2009). Comprehensive T&E of RM is not present in the literature. However, our use of RM is intended to more accurately characterize the environment in which our TE scenario will be deployed. We are interested in the following output from RM:

- topology of the TE scenario,
- accurate distance measures between BS and SS, and
- approximate radio propagation qualities.

We have validated the output of the first two items by inspection. Furthermore, RM provides a three-dimensional view of the BS and SS stations as well as vectors illustrating, with color, the signal loss as a result of the environment. This interface provides a quick “sanity check” of the outputted numerical results. Since the built-in ns-3 propagation model is the only other environment model we have available, the reasonable approximation of radio propagation produced by RM is a significant improvement.

## Gnuplot

Gnuplot is an open-source cross-platform command-line-driven graphing utility. It was created for visualization of mathematical functions and data interactively and has been under active development since 1986. Gnuplot is used extensively in the scientific community. A search on the ACM portal for articles involving the keyword, “gnuplot”, identifies nearly 300 articles. Our use of gnuplot is for the two-dimensional visualization of performance metrics such as throughput.

## Net-Measure

Net-Measure (code.google n.d.) is a C++ class that “wraps” the performance monitoring capability of ns-3 (FlowMonitor) into an easy-to-use interface. In addition, Net-Measure provides interval-timed captures of network metrics so that performance plots can be visualized (with gnuplot) over time. The implementation of the class is one C++ file.

As Net-Measure relies on the correctness of the ns-3 FlowMonitor, a personal review of the single source file implementation was sufficient to verify the correctness of the implementation. We validated, to



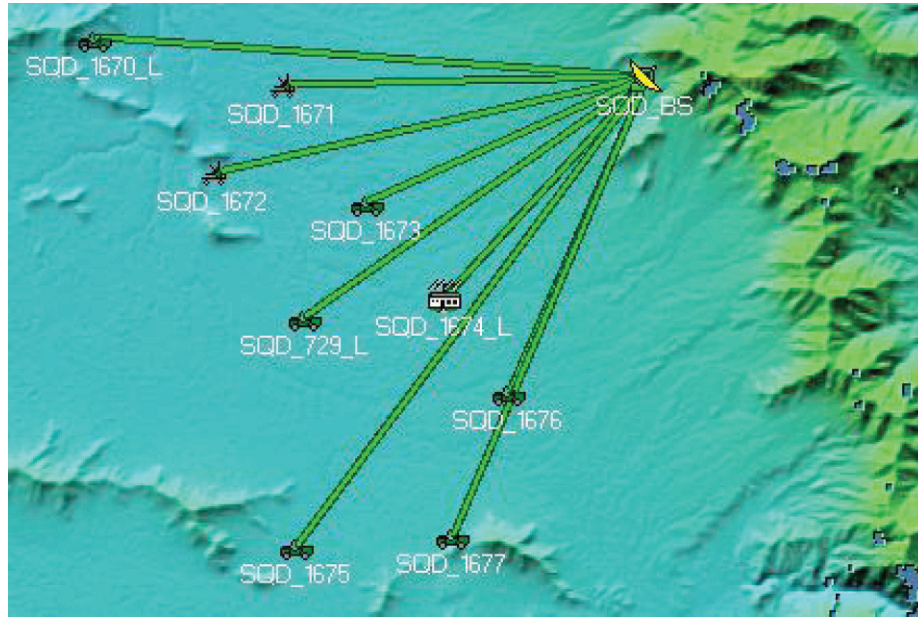


Figure 3. Worldwide Interoperability for Microwave Access (WiMAX) platoon configuration.

our satisfaction, the results of Net-Measure on three “built-in” WiMAX examples within ns-3.

### Python script

A Python script is utilized to translate the output results of RM into a more succinct text form that will be imported into our ns-3 simulation. This script is short, and its correctness is easily verified by observing the source code. We validated the correctness of the results by comparing the translated output with the input from RM.

### Integrated solution details

Figure 2 illustrates the integration and coordination of the various tools described in the previous section. We now describe the flow through this solution architecture with a specific TE use case.

A likely deployed isolated squad WiMAX cell scenario was obtained from the Communications-Electronics Research, Development, and Engineering Center (CERDEC) (see Figure 3). The topology of this deployment is not atypical of general WiMAX topologies, including commercial layouts. CERDEC also supplied simulated traffic; characterizing traffic types, rates, QoS priorities, and timings for a squad deployment.

The traffic data from CERDEC is not real data, but rather representative data obtained from the traffic generation tool, TGEN. The data has been “sanitized” for security reasons but still represents a realistic TE traffic flow pattern with multiple QoS constraints,

including situational awareness, command and control, and voice.

Our integrated solution commences with the layout of a squad topology in a selected region using RM [1] as shown in Figure 2. The output of RM is then converted with a python script into a form amenable to ns-3 [2]. A simulation run consisting of the custom use case [8], Net-Measure module [4], and a command-line-specified uplink scheduler [5] is initiated. The plot output results of the ns-3 simulation are then viewed using the Gnuplot utility [7].

This integrated solution is not unwieldy. Since we are concerned with the impact of the uplink scheduling algorithm on throughput (with QoS constraints), steps [1] and [2] need only be performed once. Components [3, 4, 5, 6, and 8] are either “hardwired” into the code, or automatically configured/selected as a result of the input. Only step [7] needs to be performed separately after each simulation run.

### Results

Figure 4 compares the performance of three different scheduling algorithms. The graph is a preliminary comparison graph we constructed utilizing a simplified simulation. We initially coded this simple simulator to verify the results of one particular published article (Mohammadi, Akl, and Behnamfar 2008b), which demonstrated an “optimal” uplink scheduling algorithm in the form of a modified 0/1 Knapsack problem.

The simple simulation compares the different scheduling algorithms in a theoretical manner in that

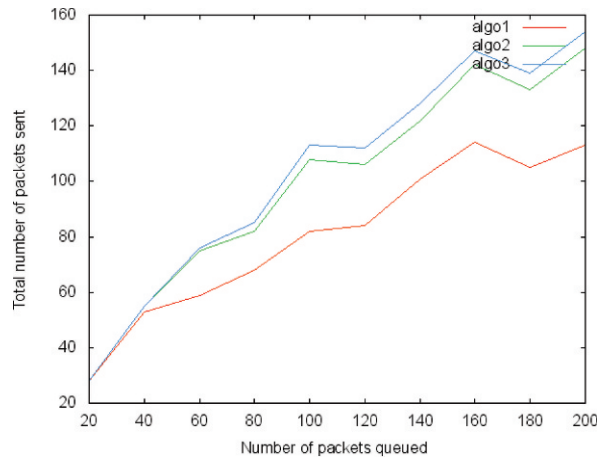


Figure 4. Simple simulation results.

the vast majority of the WiMAX infrastructure and protocols are not modeled. For instance, protocol stacks, specific application data, and propagation characteristics are not modeled. The simple simulator consists of less than 1,000 lines of code and is typical of many simulations that appear in journal articles comparing WiMAX scheduling algorithms (Mohammadi, Akl, and Behnamfar 2008a, 2008b; Wongthavarawat and Ganz 2003).

From *Figure 4*, we see that as the number of packets waiting to be sent (queued) at the SS grows, then the different algorithms distinguish themselves by performing better or worse in terms of the number of packets actually sent. Theoretically speaking, it appears that Algorithm 3 is superior.

The TE-use case consists of a set of nine squad member SS and one control center BS (see *Figure 3*). In this figure, the BS is depicted as a parabolic antenna with the label SQR\_BS. All other icons on the map are squad members. A green connecting line between the BS and an SS indicates a high-quality signal strength radio link. The distance between the BS and each SS ranges from 14 km to 32 km. Each SS consists of a 2-meter high omnidirectional antenna and uses Binary Phase Shift Keying (BPSK) 1/2 modulation. Three different uplink scheduling algorithms were evaluated.

Simulation results using the TGEN squad traffic with multiple scheduling algorithms indicated no difference in performance. *Figure 5* summarizes the results of the comparison by measuring the throughput over time for traffic between two arbitrary nodes. All three uplink algorithms yielded similar throughput. Performance between other pairs of nodes behaved similarly.

For this TE scenario, the results of our simulation indicate that any uplink scheduling algorithm can be

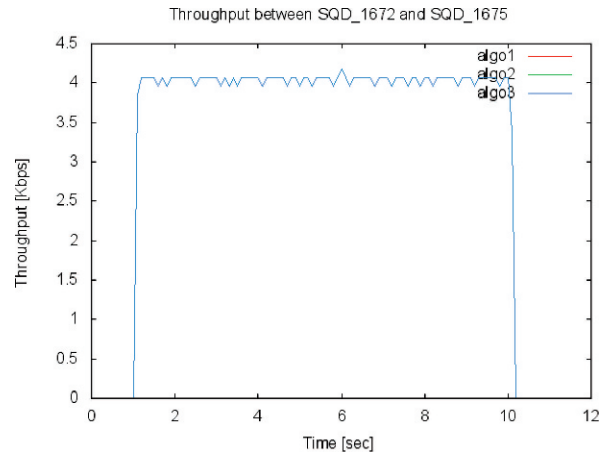


Figure 5. Net-measure results.

used with no significant change in performance. These results don't contradict the simple simulation results. Rather, they simply indicate that, for this scenario, the choice of uplink scheduler is not a factor on performance.

We note that the nature of the TGEN squad traffic is fundamentally multicast. Though ns-3 supports multicast within many models, the documentation is unclear about how to establish multicast groups attached to a BS. The results presented here substitute unicast traffic in place of multicast traffic. Nevertheless, we expect the results to be the same, as the traffic volume in the uplink direction would not increase significantly.

## Conclusion and future work

We have demonstrated integrated solution architecture for T&E of WiMAX performance on QoS-constrained TE traffic using open-source modeling and simulation tools. The solution is general in that it can be applied to other WiMAX performance-affecting variables such as modulation type, radio frequency, terrain profiles, and traffic type.

For the specific TE squad use-case we investigated, the choice of uplink scheduling algorithm resulted in no detectable degradation in performance. Our belief is that the limited volume of the TGEN squad traffic does not saturate the available bandwidth in the uplink direction. Thus, algorithms that seek to optimize bandwidth allocation perform no better than simple algorithms. With larger-scale scenarios involving more loquacious network applications, we anticipate differences.

We identify five promising avenues for continued work using this architecture. First, the characteristic multicast nature of TE communications should be modeled. The multicast facility is present in ns-3 but requires further research to determine how to use it at a

WiMAX BS. Second, larger-scale simulations, perhaps at the platoon or even battalion level, can be pursued. Third, WiMAX TE scenarios involving a broader range of applications exhibiting greater traffic volume and more varied QoS constraints can be considered. Such a set of applications might include tactically important text chat, white board, streaming video, and application sharing. Fourth, a level of validation can be obtained by implementing the same scenario in another simulator (e.g., OPNET). Fifth, the development of a GUI to “seamlessly” integrate the various open-source and freeware tools would be a useful endeavor.<sup>1</sup> □

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## Endnotes

<sup>1</sup>Disclaimer: The authors' affiliations with SPAWAR Atlantic are provided for identification purposes only and are not intended to convey or imply the above organization's concurrence with or support for the positions, opinions, or viewpoints expressed by the authors.

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